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VLF -MT Survey around Nakadake crater at Aso Volcano

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Abstract. Shallow resistivity structure around Nakadake craters has been revealed by extensive VLF- MT survey from August to October 2006. This structure comprises a varied resistivity value at the upper and bottom layer of the western flank of craters; a conductive upper layer at the fourth Crater; and a resistive upper layer at southern part of craters. The conductive value of second layer at a line in the western flank and southern part of craters at several ten meter depth, interpreted as water saturated, and high resistivity at second line of western flank of craters as sheet of lava and at fourth crater is interpreted as lava rock . At western flank of craters, we found the resistivity value and the depth of second layer decrease in depth with decreasing of distance to craters line.

1. Introduction

Aso Volcano is located on the Kyushu island, in the south-western , part of Japan. Nakadake, one of the youngest volcanoes in the central cone complex of Aso Volcano, has a currently active crater, named first Crater, and other 6 craters in the NNW-SSE direction. The first crater has been ejecting large quantities of ash, mud and scoriaceous ejecta in strombolian type eruptions every years [1], and is also the local of episodes of continuous volcanic tremors which accompany the volcanic activity. The 1st crater diameter is about 400 m. During quiet volcanic states, a crater lake is usually present in the bottom of the crater, the surface temperature of the lake being about 600^0 C. Figure 1 shows the location of Nakadake craters and mapping points of the surveys.

Many active volcanoes bear a hydrothermal fluid system within their edifice. Such fluid easily infiltrates within permeable ground and efficiently transports heat because of its large heat capacity whichever the origin is precipitation from the atmosphere or magmatic volatile. Electrical resistivity is one of the most useful methods to examine the thermal process taking place [2], because the electrical resistivity of the ground highly depends on the temperature and the concentration of water and volcanic gas in the permeable porous medium that usually composes the volcanic edifice [3].

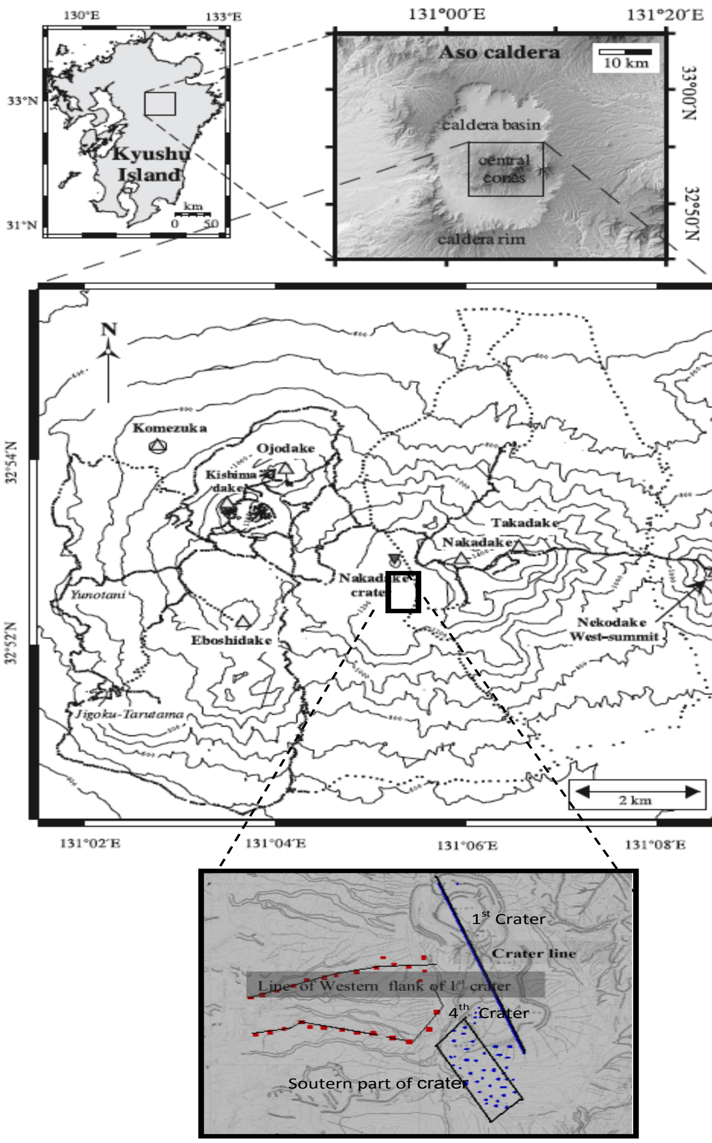

Figure 1. Location map of the study field. red and blue dots show the measurement points of VLF-MT.

In this paper, we carried out VLF-MT survey to infer the shallow resistivity structure around the craters and discuss the hydrothermal system beneath crater rim of Nakadake craters. Interaction between subsurface water and heat will be discussed in relation to conductive structure. VLF signals (15-30 kHz) are used to study the variation of the electrical conductivity in the upper few hundred metres of the Earth's crust. The variation in EM field components relate to the electrical structure of the subsurface. The VLF resistivity mode (VLF-MT), which also utilizes electric field, was proposed by Collet and Becker [4]. The VLF method maps shallow depth inhomogeneity and widely used in mineral exploration, groundwater exploration and waste management and in structural studies.

VLF-MT measurements are used to record the horizontal electric field component and an orthogonal horizontal magnetic field. Because of large distance from the VLF transmitter, the primary EM fields can be regarded as plane waves. It is possible to use either the E- or H- polarization. For E-polarization, where electric field is parallel with the geological strike, apparent resistivity, ϱ_a, and impedance phase, ϕ, computed from the horizontal electric field E_y and magnetic field H_z are given by the formula:

$$\rho_a = \frac{1}{\mu\omega}\left|\frac{E_x}{H_y}\right|^2 = \frac{1}{\mu\omega}|Z|^2 \tag{1}$$

and

$$\emptyset = arctan\left[\frac{im(E_x/H_y)}{Re(E_x/H_y)}\right] \tag{2}$$

where μ=μ0 is the magnetic permeability of free space and, ω is anguler frequency of measurement, and Zxy is the surface impedance. The skin depth, δ, is defined as the depth of penetration at which the electromagnetic field reduces to 1/e of its value at the surface of that medium, it is given by :

$$\delta = \left(\frac{2}{\omega\mu\sigma}\right)^{1/2} (unit\ \ length) \tag{3}$$

where σ is conductivity. In practice, Observed VLF-MT data are represented by apparent resistivity, ϱa, and impedance phase, ϕ. Field component Ex in eqs.(1) and (2) is obtained by applying the finite element technique with the Galerkin process directly to Maxwell's equations; the other field components can be computed from Maxwell equations by numerical differentiation. The very fast simulated annealing (VFSA) approach is used as the procedure of optimization in this inversion [5].

2. Very Low Frequency – Resistivity (VLF-MT) surveys.

The mapping points are located on western flank of crater and southern part of craters. The points of VLF-MT survey is shown in Figure 1, line survey on the western flank of the craters, within the fourth crater, and southern part of the craters. As a source is used VLF-MT receiver is VLF radio wave station (JJI; 22.2 kHz) for submarine communications, which located about 100 km SSW away from the present study area. The resistivity structure around crater rim of Nakadake crater was established by VLF (Very Low Resistivity) R or MT surveys along August – October 2006.

The results are presented in three areas that are western flank of craters, southern part of craters and fourth crater. From previous research [1,6], the results of resistivity sounding are composed of fine volcanic ashes for the surface, the second layer is pilled scoriae and the western and southern part of the lowest layer is formed of the high resistive Kusasenri lava rocks. The very low resistivities at the crater of Nakadake (Sunasenri) suggest these regions are composed of scoriae and volcanics ashes. While the high resistive layer found at Umanose and Western slope out the crater, represent the existence of lava sheets.

The area at western flank of craters, has two line surveys, Figure 1. The results, Figure 2, shows the apparent resistivity and impedance phase as function of distance from craters line. It indicates that the various results for three time survey, apparent resistivity tend to decrease and change in impedance phase at same distance from crater line. The second area, Figure 3., is southern part of crater, we have made in contour of apparent resistivity and impedance phase for all data of surveys. These contour show that various apparent resistivity and impedance phase at several locations indicate different resistivity structure of subsurface. The last area is fourth crater, Figure 4, low apparent resistivity and contras in impedance phase contour indicate location of the lower resistivity along the middle of fourth crater.

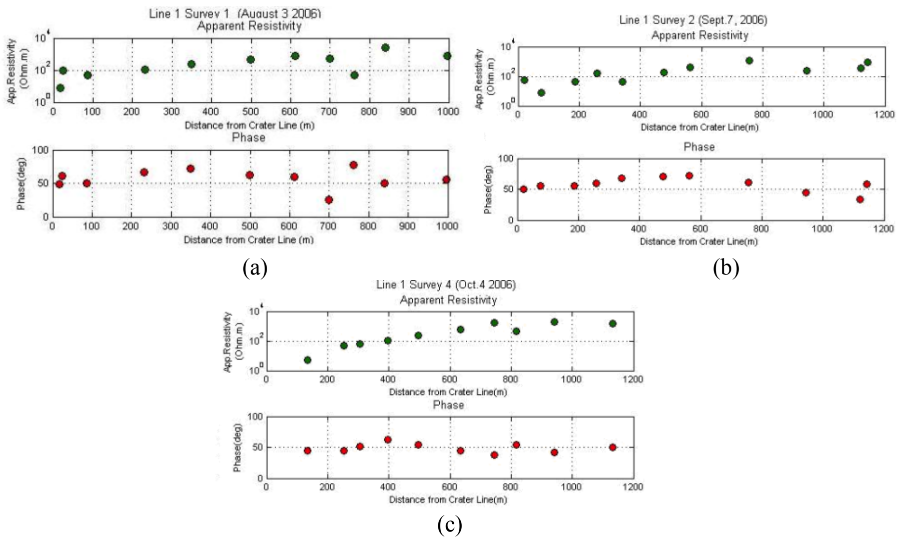

Figure 2. Apparent resistivity and impedance phase of Line 1 of VLF-MT Survey (a) August 3, 2006 (b) Sept. 7, 2006 (c) Oct. 4 2006

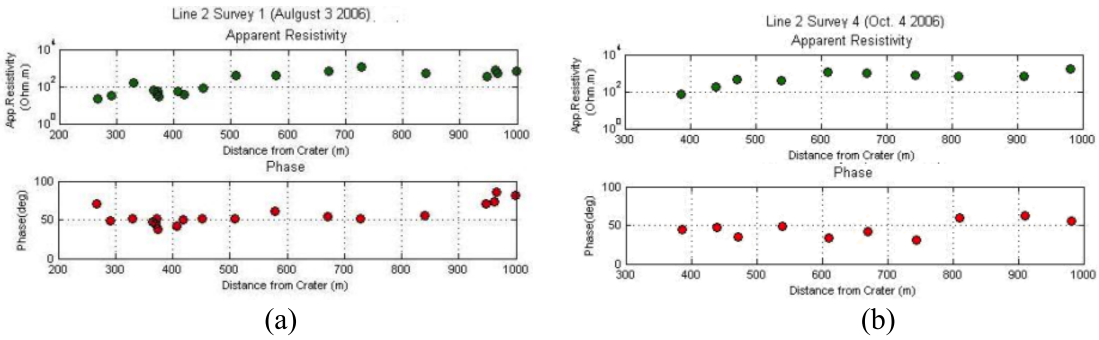

Figure 3. Apparent resistivity and impedance phase of Line 2 at Western flank of craters. Survey (a) August 3, 2006 (b) Oct. 4 2006

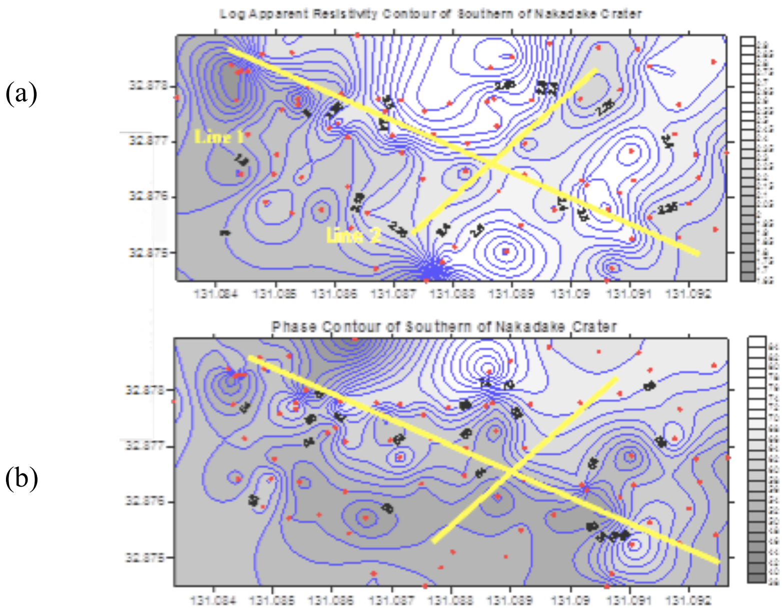

Figure 4. (a). Apparent Resistivity and (b) Impedance phase Contour, at Southern part of Craters

4. VLF-MT Data Inversion and Discussion

The laterally constrained two layer inversion of VLF-MT data algorithm, developed by Pirttijärvi,M [7], was applied to interpret electromagnetic VLF-MT data (apparent resistivity and impedance phase) measured along a single profile at a single frequency. The inversion is made separately for each data point using a one-dimensional two-layer earth model. As such the program suits well the interpretation of the thickness and resistivity of relatively thin resistive (soil and till) layers and the resistivity variations of the basement rocks. Note that the inversion model is still only one-dimensional and that the interpretation results actually yield a pseudosection of the 2-D resistivity distribution.

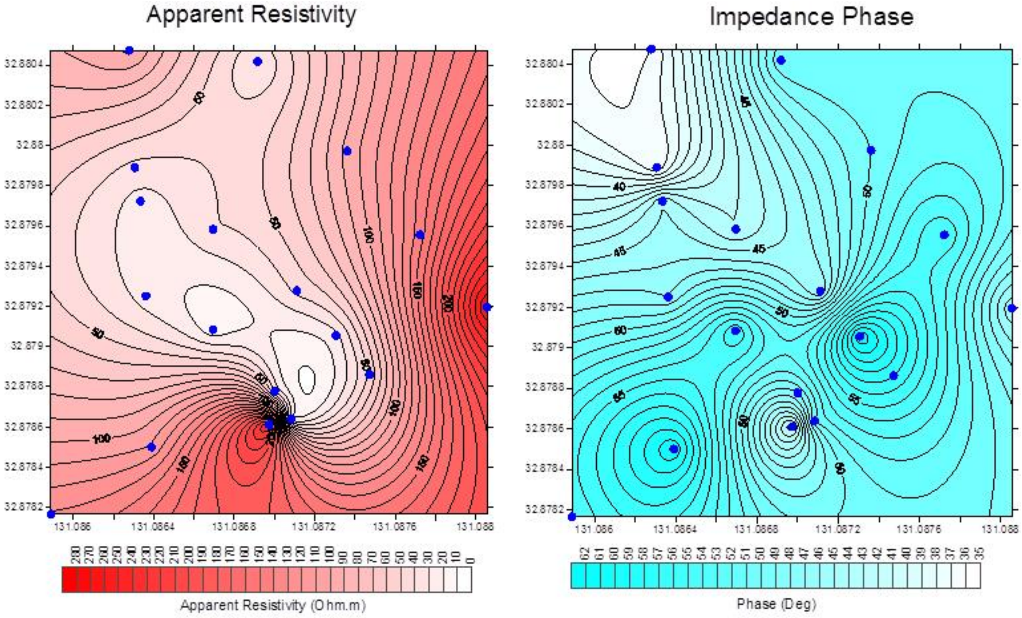

Figure 5. Apparent Resistivity and Impedance phase Contour at fourth Crater

Starting from an initial model linearized inversion with adaptive damping is used to optimize the thickness and the resistivity of the overburden layer and the resistivity of the basement so that the model minimizes the error between the measured and the computed VLF-MT data. Laterally constrained inversion is obtained by minimizing the roughness of the model that is the variation of the model parameters between neighboring points, together with the data error. As a result a smoothly varying (Occam inversion) model is obtained. The roughness and/or the fix/free status the parameters can be set manually to allow discontinuities and to incorporate a priori data in the model.

Source for the VLF-MT measurement use a signal frequency of 22.2 kHz. The quantitative interpretation, equivalent with other geophysical methods, relies on model calculation into the relationship between observed data and real geological condition to yield a quantitative interpretation. The inversion modeling calculates the two-layer model data, using of the measured apparent resistivity. This inversion result shows that the second layer has lower resistivity. It is less than 50 Ωm at 3-10 meters deep and 0-50 meters distant from the crater line (Figure.6a). At the depth of 2-70 meters and the distance of 50 to 1000 meters from the crater, the resistivity is around 50 to 100 Ωm. The inversion result of second survey was convergence with 13,52% for data RMS error and 0.43% model RMS (Figure. 6b) and third survey was convergence with 16.51% for data RMS error and 0.56% model RMS (Figure.6c). Generally, these results show the increasing resistivity of second layer comparing to first survey data.

Generally, the inversion result of third survey shows increasing resistivity value for all , for 125 to 400 meter from crater line resistivity of second layer is 48 to 100 Ωm with 2 to10 m in depth, for the resistivity from 400 to 634 meter is 100-300 Ωm with 10-20 in depth, the resistivity is higher than 300 Ωm for distance from crater more than 634 meter with variation in depth (9 to 50 m). For the second line, the inversion results of first survey was convergence with 12.47% for data RMS error and 0.65% for model RMS. These results show that upper layer is more resistive than the second layer with variation in depth from 13 to 90 meter (Figure 7) , inversely at near crater upper layer more conductive.

For two parallel lines (line-1 and line-2) at 4th crater (Figure 8), the result shows the depth variation of the bedrock (15 to 36 meters). Line-1 of this crater is deeper than eastern part (line-2). From inversion result, the resistivity profile of the crater shows the different structure among line-1 and line-2. The higher resistivity of line-1, compares to line-2, can be interpreted as the domination of lava-rock due to the volcanic activity. Whilst, the lower resistivity is due to the heat below the crater. At the southern part, two perpendicular lines show consistence of resistivity structure, which is more resistive at the upper layer. The decreasing value of the resistivity near the crater line is influence of the volcanic underneath the crater.

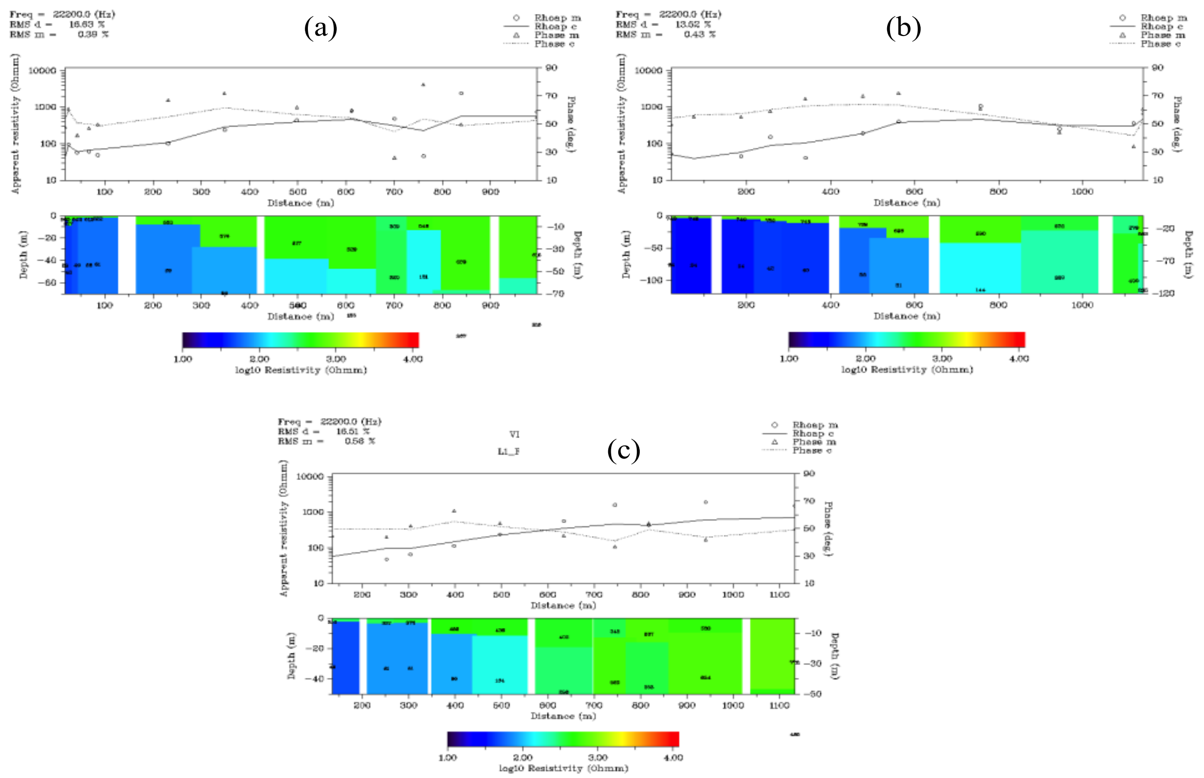

Figure 6. Inversion results of first line at western flank of craters (a) Survey at August 6, 2006; (b) Survey at September 7, 2006; (c) Survey at October 4, 2006

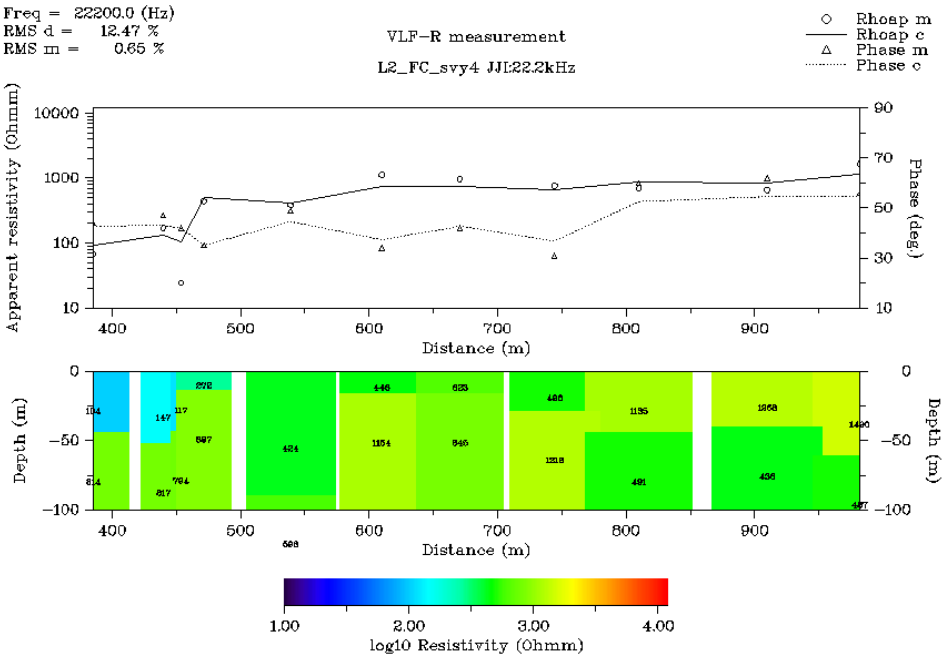

Figure 7. Inversion results of second line at western flank of craters

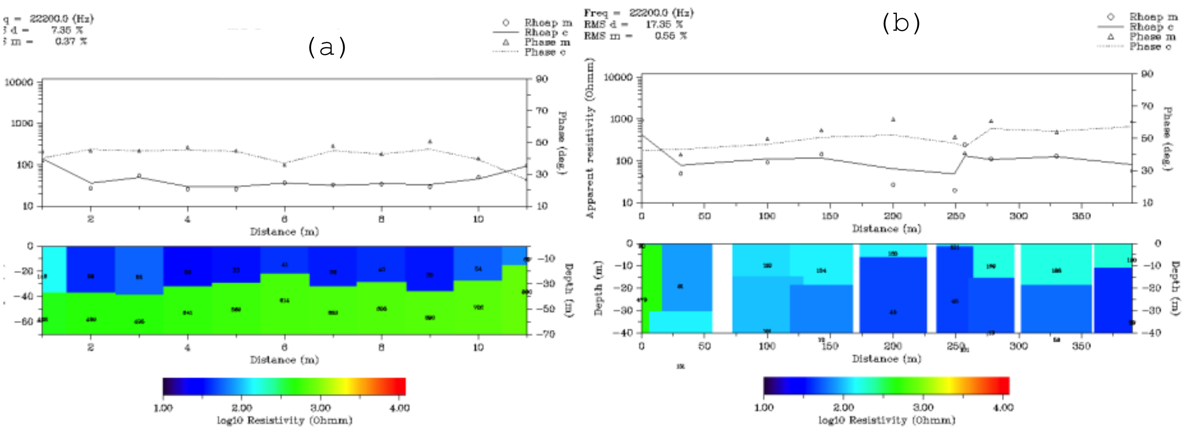

Figure 8. Inversion results of fourth crater (a) line 1 (b) line 2

5. Conclusions

In this study, inverted resistivity revealed general futures of upper and bottom layer. It can be conclude that at western flank of craters has higher resistivity second layer indicate lava sheet and the increasing of resistivity for second survey is caused decreasing groundwater as dominant factor of resistivty value of rock, inversely, for line 1 more conductive of second layer lead to suggestion that shallow subsurface of few meters in depth indicated is repeated heated and supplied by groundwater.
Phenomena low resistiviy of surface at fourth crater reveal dominated lava rock of second layer. For upper layer of fourth crater, low resistivity in the top layer thicker is suggested by heat from beneath the crater. The phenomena low resistivity of upper layer in southern part of crater is suggest by water saturated layer through interaction between magma, juvenile gas, and groundwater.

Acknowledgments

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